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no. 5

[Reprinted from the BULLETIN OF THE SOCIETY FOR THE PROMOTION OF ENGINEERING EDUCATION, Volume IV., No. 5, 1914.]

HYDRAULIC ENGINEERING EDUCATION.

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THE AIM OF ENGINEERING EDUCATION.

All who have given much thought to the subject of education will agree with me that the purpose of education is not so much to impart knowledge as to train the student to acquire knowledge. The purpose of technical education, therefore, is not so much to impart technical knowledge to the student as to furnish the training which will enable him to understand and investigate the conditions which surround a problem, to determine the fundamental principles on which its successful solution depends, to ascertain and analyze the elements which influence or modify it, to design the structures and works needed for its successful development, and to supervise the proper construction of such structures or works and carry them to a consummation of successful and economical completion. This, in my judgment, is the essential aim of engineering education.

REQUISITES IN AN ENGINEER.

The engineer must have a comprehensive understanding of the elements that underlie his problem and on which its proper solution depends. He must know what and how to investigate, and how to analyze and weigh the influence of every factor involved. He must be able to see or determine the value and effect of each element in the problem, and he must know where the knowledge needed for these ends is available and how to acquire it. He must understand ways and means as affecting both construction and operation, and, so far as possible, he must have developed his judgment, sense of justice and equity, and common sense.

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Judgment can be developed by experience only, but the tendency of technical education is rather to the detriment of judgment. If text-books and instructors are considered infallible, if their lectures and dicta are to be taken without question, the development of judgment is certainly not stimulated. An earnest effort should be made to point out the limits of theory and the point where judgment and speculation begin. The use and abuse of formulas should be noted, and their limitations pointed out and emphasized. Every experienced engineer recognizes the convenience of formulas but also understands the danger of their careless application. I know no better way of encouraging judgment or emphasizing the limitations of formulas than by a careful and detailed study of actual professional problems where the uncertainties are clearly pointed out. I have had a great many young men in my employ in private practice and have found that in a great many cases they were largely dependent upon formulas with which they had become familiar in their college course, often assuming them to be absolutely dependable when frequently they were not applicable to the particular cases at hand. Again, in many cases, if the formulas were not available, the work at hand was attacked with great difficulty.

ETHICAL PRINCIPLES.

One of the most important factors of technical education in every line is the ethical attitude which is necessary for engineering success. This can not well be taken up as a special study, but should be introduced by instructors whenever the time seems appropriate.

Most practicing engineers recognize the fact that a true view of ethical relations is fully as important as technical knowledge, and no student should leave his university without being impressed with the more important ethical principles. One of the most important of these is a knowledge of self-limitation, and an appreciation of the fact that success is mainly due to hard work and not to great brilliancy. The student must be brought to appreciate his own limitations and the meagerness of his knowledge, and must learn that success in any line is dependent on thorough, hard, conscientious and intelligent work. Most so-called men of genius have accomplished results by constant and unremitting application, by untiring drudgery, rather than by great brilliancy; and all that is most worth while in life is accomplished or secured in the same manner. Opportunity is undoubtedly important, but hard work usually creates opportunity, and no man accomplishes true success without these elements ingrained in his character.

Another characteristic of success is dependability. No amount of knowledge or work can take the place of this attribute. The man who can be depended upon is ever in demand and if he has also acquired a high degree of technical training and an appetite for hard work, his success, barring accidents, is assured.

The Content of a Technical Course.

The amount of knowledge that can be retained in the mind at any one time is exceedingly limited, and in discussing education it must be understood that the time spent in the university course as well as the mental capacity of the student are both too limited for the acquisition of anything more than the elements of knowledge needed by the practicing engineer.

For the purpose of technical education, instruction is required in the following:

1. In the fundamental principles of those sciences on which the practice of the engineer necessarily depends.
2. In those methods and calculations which must be applied in such practice.
3. There should be included to as great a degree as possible instruction in those human elements that concern the personal relationship of the engineer with his fellows, with his clients, with contractors, and with the public, and also those matters of judgment, equity and ethics upon which the highest success of the engineer depends no less than upon his technical knowledge.

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The teaching of such principles is difficult but essential, and should be introduced in the technical course with professional subjects. It can, I believe, come best from those instructors of more mature years who are most closely in touch with practice.

While the average student objects to ''preaching,'' I find that no other subjects so intensely interest a class of advanced students as those which have to do with the relationship of the engineer to life and to the ethics of professional practice.

BREADTH OF EDUCATION DESIRABLE.

All knowledge is more or less related, and every subject bears more or less directly on every other subject. It has been said that if any man knows all that can be known of any one subject he knows all that there is to be known of every other subject. Such a comprehensive knowledge is of course ideal and impossible of realization, but a broad foundation of many subjects is necessary to a true appreciation of any one. This is especially true of technical knowledge; and for a broad knowledge of any specialty it is both desirable and necessary that the student have a general knowledge at least of other specialties.

DANGER OF EXTREME SPECIALIZATION.

There is, perhaps, no more narrow man than the specialist who knows nothing of aught but his specialty; he is an unsafe guide except along his own narrow lines, for when his lines cross or run parallel with other subjects, he has no true perspective of relative importance or of relative values.

It has been said that if you are sick and go to a tailor, his prescription will be a new suit of clothes. Every thoughtful engineer will realize that his personal experience and bias will influence his recommendation. Recently a proposition was under consideration that involved the installation of two pumping engines of six million gallons capacity in a location where it was undesirable to construct a boiler plant and where in conseqence power had to be transmitted in one form or another for about a quarter of a mile. Various electrical engineers who were brought into the discussion uniformly recommended the use of electrical generation and transmission. A large steam-electric installation was already available in the main plant, and the electrical engineers advised the use of that plant which, however, was about four times too large. When it was pointed out that the efficiency would be very low on account of the large size of the generating plant, the electrical engineers advised the installation of a steam-electric plant of proper size for the work to be done. After due consideration of the proposition, steam transmission, the steam pipes being carefully insulated, was installed. The steam consumption of the plant actually installed was about half of what it would have been with a special electrical plant designed for the service, and about one-quarter of what it would have been with the large plant that was already installed; and at half and quarter loads, at which points the plant operated a considerable portion of the time, the saving was very much greater. The error in the advice of the electrical engineers is therefore obvious. The tendency of the specialist is always to advise the application of his specialty.

I believe that one of the most important elements in the instruction of the young engineer is to lead him to appreciate not only his own specialty but to give him a correct appreciation of the specialties of others. The engineer who is educated in only one specialty and has not the knowledge necessary to compare it with others, is poorly prepared for professional life, and his training will not give the best results to either himself or his clients.

Specialization is, in my opinion, a serious mistake if carried far in a university course if the desire is to educate engineers instead of training skilled workmen. The ideal university for the education of the engineer is not a trade school. The education should be largely general, and special branches should be so handled as to broaden and not to narrow the student; they should be considered with relation to other lines with which they may have to be compared.

ENGINEERING COURSES FAIRLY SATISFACTORY.

In most branches of engineering, the courses of our engineering schools are fairly satisfactory. The principles and methods on which investigations and practice must rest are fairly well covered, and the young engineer when he leaves his technical school is fairly well prepared to undertake the minor calculations and designs in the practice of his profession. He still needs experience, postgraduate study and investigation, which are necessary for more advanced work and can be obtained to the best advantage concomitant with the practice of his profession.

THE WEAKNESS IN HYDRAULIC ENGINEERING EDUCATION.

In the teaching of hydraulic engineering there is a decided weakness in the professional courses pursued in most schools. The great loss of life and property in recent floods; the similar losses caused by the failures of dams and reservoirs within recent year, and the errors in estimating hydraulic resources, resulting in the partial or complete financial failure of many hydraulic projects in irrigation, water power and water supply, point to the great need of fundamental education along hydrological lines both of the people as a whole and of engineers on whose shoulders more particularly rests the responsibility for the success of these various projects.

Since the recent disastrous floods, the lack of exact information has become especially apparent. A great deal of so-called knowledge concerning hydraulic and hydrological matters is simply speculation, or may even be classed as fable and superstition, which even a little investigation would show to be erroneous. As examples of these errors into which both business men and engineers are frequently involved, numerous instances might be cited. Mr. James J. Hill, in an article in one of the recent magazines, points out that the building of levees along the Mississippi River is a failure because the river is gradually building up its bed almost as fast as the levees are constructed. Now it is a fact which has been demonstrated by some 400,000 soundings by the Mississippi River Commission, that the Mississippi River is not building up its bed, and the proposition laid down as an axiom by Mr. Hill is entirely in error. Another popular fallacy is the universal adaptability of reservoirs to prevent floods, that reservoirs furnish the solution of flood prevention. In a recent paper by Colonel Townsend, president of the Mississippi River Commission, delivered at the Drainage Congress in St. Louis, he made the following statement, which can be readily verified. Taking into account the length of time in which the water would reach Cairo from Pittsburgh, St. Paul and St. Joseph, even if at that time reservoirs had been available with capacity sufficient to have cut off the flow of the Mississippi above St. Paul, of the Monongahela and the Allegheny above Pittsburgh and of the Missouri above St. Joseph, the height of the water at Cairo would have been reduced but six inches. I know of no better illustration of the limitations of reservoirs as a universal panacea for floods.

Not long ago I received a letter from the editor of an engineering magazine calling attention to the control of the Chagres River by the Gatun Dam, saying he hoped that all engineers would unite in the recommendation to apply this same principle to the control of the Mississippi River. Could any proposition be more absurd? Even a layman should realize that physical conditions must control, and that no scheme of flood control is universally or even generally adaptable.

The popular clamor for waterways as a sure cure for commercial and transportation difficulties, regardless of detailed consideration and investigation, and the theory of the universal influence of forests in conserving, equalizing and improving the flow of streams, are examples of erroneous hydrological ideas that will not bear the test of careful and thoughtful investigation. These subjects should be so considered and discussed in a hydraulic engineering course that the future hydraulic engineer will realize the necessity for careful investigation and the determination of the actual value and influence of a given structure or plan of development on the betterments desired, and not be misled by popular clamor and irrational assumptions.

NECESSITY FOR HYDROLOGICAL EDUCATION.

Experience in the field has demonstrated the fact that more failures have resulted in various projects of hydraulic engineering from a lack of an adequate conception, on the part of the designing engineer, of the fundamental principles of hydrology and of the importance of hydrological factors, than from defects in the design or construction of the various structures involved. In many cases the engineer has not possessed sufficient knowledge to appreciate the necessity for hydrological investigation and study, and very frequently has ignorantly made unwarranted assumptions and neglected any investigation whatsoever, because of the lack of such appreciation.

As a result of this lack of appreciation of the fundamental basis on which every sound hydraulic project must rest, we find numerous irrigation projects completed at large expense but without adequate water supply; water power plants constructed on streams not having sufficient available flow, or with such irregular flows as to make the projects entire or practical failures; spillways and gates in dams constructed with inadequate capacities for the passage of extreme floods; pumping stations constructed to utilize supplies of water which are too limited for the purposes for which they were intended, or with supplies polluted, or otherwise undesirable; communities and industries located in situations where they are subject to serious overflow and unnecessary flood damage; protecting works built with no adequate idea of the maximum necessities of the case, or their effect on flood heights: drainage enterprises undertaken with no adequate knowledge of the flood capacities which must necessarily be provided for extreme conditions. In many ways unnecessary losses are frequently entailed which have been due largely to the fact that the attention of hydraulic engineers has not been called to the importance of hydrological information, the sources from which such information can be obtained, or the necessity and methods of undertaking hydrological investigation and study.

NECESSARY LIMITATIONS OF TECHNICAL INSTRUCTION.

The subjects considered essential in technical education are so numerous that it is very evident that scarcely more than the barest outline of any technical subject can be acquired within the necessary limits of a university course. It is, of course, manifest that in the brief time available for professional studies in technical schools the lines of instruction must be more or less limited, and that a full consideration of any professional subject must be left for the investigation and study of the young engineer after he has begun actual practice of his profession. No professional study can be attempted except in a most elementary and incomplete manner; but in every case the student should receive instructions as to what to study, and how to investigate in his own special line of professional practice.

For example, the subject of water supply, which is treated in one semester in most universities, usually occupies the time of the student about one hundred and fifty hours, or the equivalent of fifteen or twenty days. During this limited time, instruction must be given in the entire subject of water supply, including the sources of supply, development of underground and surface waters, distribution systems, standpipes, reservoirs, pumping machinery, and numerous other subjects. Any practicing engineer will spend usually more time than can be given to this entire subject on a single phase of a single proposition which may come before him. It is therefore obvious that such a course can cover only briefly the most important points, and that the student when he leaves his university knows nothing about the comprehensive subject of water supplies except how to investigate and study the subject. To instruct the student in methods of investigation and study is the only attempt that can reasonably be made in the teaching of any professional subject such as water supply, water power, irrigation, drainage, etc. This is the object of such a university course.

THE CONFIRMATION OF TECHNICAL INSTRUCTION.

Technical knowledge to be of the greatest value must be confirmed by practice. Even the fundamental principles acquired by the student become truly his only after they have been demonstrated under many conditions and in many places. When the statement of the teacher and of the text has been fully investigated and verified, then and only then is the knowledge truly acquired. It must, therefore, be understood that university work to be of real value must be supplemented by study, observation, practice and experience.

The deficiencies in hydrological training are well illustrated by the following example. I had occasion only a few years ago to examine an irrigation project in the arid west that had been laid out by a graduate of one of our engineering institutions. The design, so far as the structural features were concerned, seemed to be excellent. When the question of water supply was discussed, the engineer in charge stated, "Oh, there is plenty of water, there is no question about that; I have been around that stream for several months, and I know there is always plenty of water." Later, when the matter was examined in detail, it was found that there was not over one third to one fifth of the water that would be required, and the engineer finally remarked, "Well, to be honest, I did not know how to make an estimate of the water supply or how to investigate it."

On this same project, an older and more experienced practicing engineer, who was in charge of a similar project costing over three million dollars, visited the same work, and a rainstorm occurred at the time so heavy that the gullies were running full and he had to wait several hours before making some small creek crossings. From his chance experience, under most unusual conditions, he said, "Gentlemen, you have water enough to irrigate this whole valley." An investigation of the water supply showed so little water that the project was rejected as impracticable.

I have seen so many errors of this kind in my examination of projects in the various lines of hydraulic engineering that

I believe engineering schools should give some attention to this subject. I do not wish to imply that a great amount of time is necessary, but rather to express a belief that the attention of the student should be drawn to these important hydrological subjects and that some systematic course of limited extent should be arranged to point out the dangers in hydraulic projects of ill-advised plans based on inadequate knowledge. The source and necessity of such knowledge should be made plain to the student, so that when the time comes he will know what his problem is and how to study it.

The teacher cannot expect to impart to the student the knowledge that can be assimilated only by long years of experience. Even the engineer in practice can keep in mind only those things with which he is in daily contact: he must look the others up; he must study them; he must acquire and reacquire them as he needs them.

Educational ideals are by no means fixed; they must grow and develop; they must change with the times and the circumstances. In my judgment, most engineering courses can be greatly improved by a judicious introduction of the personal and ethical factors. In hydraulic engineering courses much more attention should be given to fundamental principles which have in general been too long neglected.

The ordinary engineering course provides fairly complete instruction in mathematics, strength of materials, design of structures, and in the calculation of problems connected with those physical phenomena on which the practical success of engineering structures must depend. The whole training of the engineer emphasizes the necessity of a knowledge of the principles of design in order to give adequate strength and stability to the structures to be designed and installed. While errors in such designs are only too abundant, they are, in hydraulic-engineering projects, much more limited than the more fundamental errors that are due purely to the lack of appreciation of the very element of the problem on which success most depends.

No engineer would attempt to design the physical structures of a water-works system or water-power plant without endeavoring to acquaint himself with the principles and practices on which the successful construction of such structures must depend; and yet, the water supplies on which the success of these projects is entirely dependent are frequently only superficially investigated, or the sufficiency of supply assumed. It would, therefore, seem illogical that our schools should provide instruction in these technical subjects which can readily be taken up by the engineer in post-graduate study, either in college or out, and fail to provide a thorough course in the fundamental underlying principles of hydrology on which the success of all such projects *must* largely depend.

A certain amount of professional study in a technical school is undoubtedly desirable inasmuch as such study permits instruction in the methods of investigation and design, and points out the application of the previous theoretical work of the student. It seems illogical, however, that such professional study should be pursued to an extent which will cause the neglect of a line of instruction so important to the ultimate success of the hydraulic engineer.

Hydrology.

Hydrology should treat of the laws of the existence and distribution of water over the earth's surface and within the geological strata, and of its sanitary, agricultural and commercial relation. It should discuss hydro-meteorology principally in relation to the occurrence, distribution, variation and disposal of rainfall and the run-off resulting therefrom, in drought and in flood. It should discuss the modifications of the run-off caused by evaporation, topography, geology, temperature, and various other factors, and the variation in run-off as the factors vary in importance. The great variations in the unit run-off under similar rainfall conditions but different physical conditions, and under similar physical conditions but different rainfall conditions, should be studied, and the marked differences which arise in different parts of the country depending on these differences in conditions should be discussed and appreciated. The effects of storage, of cultivation, of forestation, and of other artificial physical modifications of the drainage area on the flow of streams should also be discussed.

The study should include hydro-geology, or the occurrence of water in the strata, and the laws of its occurrence and flow. This must presuppose or include a sufficient study of general geology to give a comprehension of the geographical limitations which must be expected in hydrographic conditions, and the modifications due to geological changes. Water as a geological agent should be discussed, and through such discussion and study a comprehension of the birth, the growth, and the development of drainage systems and of rivers attained. The apparent lawless and erratic action of streams will be thus found to follow laws more or less distinct and which must be studied and comprehended before intelligent river conservation becomes possible.

The rainfall and other accompanying phenomena are proverbially inconsistent; and yet the study of hydrology shows that there are limitations to such inconsistencies, which limitations are quite as narrow and exact as those that arise in other engineering fields which must be cared for by the "factor of safety," which is simply a "factor of inconsistency" in the qualities or occurrences of conditions with which the engineer always has to deal.

In the studies of water supply and storage which are offered in most engineering schools, various hydrological subjects are briefly discussed. In the study of geology and meteorology, which studies are sometimes included in the engineering courses, some of these subjects are also treated. Too often, however, mere facts and figures are presented concerning various phenomena, but such facts and figures are seldom correlated and the attempt is seldom made to establish relationships from which conclusions can be drawn and on the intelligent use of which the success of hydraulic work must depend.

In no work on the subject of irrigation, with which I am familiar, is the relation of rainfall to run-off, or the value and limitations of comparative hydrography, discussed even in a limited way, nor is any method of investigation pointed out.

In very few instances is the subject of hydrology systematically taught in a manner sufficiently complete to afford a reasonable basis for the investigation and study necessary to the successful practice of the hydraulic engineer, or even to a sufficient extent to give the engineer a reasonable appreciation of the importance and necessity of such study and investigation. In many cases the student enters professional life with no appreciation of this subject, and with no knowledge of the availability of the great fund of hydrological information which has been accumulated at the expense of much time and labor, and as a result of the success and the failure of many hydraulic projects. Surely our engineering schools should add this important subject of hydrology to their curricula.